TITLE OF THE INVENTION

Vehicle Bumper Structure

CROSS-REFERENCE TO RELATED APPLICATION

This application claims, under 35 USC 119, priorities of Japanese Patent Applications No. 2003-057707, filed March 4, 2003 and No. 2003-120578, filed April 24, 2003, disclosures of which, inclusive of the specifications, claims and drawings, are hereby incorporated by reference herein.

BACKGROUND OF THE INVENTION

Field of the Invention:

This invention relates to a bumper for attachment to a front of a vehicle such as an automobile.

Description of Prior Art:

A front bumper of an automobile generally serves to prevent damages of the automobile body at a time of collision of the automobile traveling at a speed of 10 km/hour or less with an object such as another automobile or a wall.

Shown in FIG. 14 is one example of such a bumper structure which includes a tubular bumper beam 22, an energy absorbing foam material 23 overlying a front wall of the bumper beam 22, and a bumper fascia 21 overlying the foam material 23. The foam material 23 is designed to absorb a collision energy and to restore to the original shape even when subjected to repeated collision impact. Therefore, the maximum strain of the foam material is designed such that the foam material can maintain its restoration force even when subjected to a large collision impact. To this end, the foam material 23 is required to have a large thickness in the front to rear direction and a relatively high hardness.

With such a construction, however, pedestrians are likely to be seriously injured by collision an automobile having such a bumper. Recently, there is an increasing demand for a vehicle bumper structure which can protect a pedestrian on the occasion of collision with an automobile. Thus, the energy absorbing foam material is required to be made of a relatively soft material having a low compression modulus, so that the leg impact can be reduced and serious knee injury can be avoided.

However, since the recent cars are designed to pursue energy saving, an increased inside occupation space and good appearance, the bumper is required to be compact and light in weight.

At present, no bumper structures on the market can satisfy simultaneously the requirements of (1) prevention of damages of the vehicle, (2) protection of pedestrians and (3) compact and light weight structure.

To meet with the above requirements (1) and (2), a though might occur to use a two-layer structure in which a relatively soft foam material for protecting pedestrians is provided on a front of a relatively hard foam material for preventing vehicle damages. In this case, however, the requirement (3) cannot be met. When the length of the soft foam material along the front-to-rear direction is reduced, collision with a pedestrian causes "bottoming out" of the foam material and generates a large load to cause injury of the pedestrian. Moreover, with the above two-layer structure, it is difficult to maintain the performance of the soft foam material, because collision of the vehicle against a wall or another vehicle will generate in the soft foam material a strain which is beyond the maximum strain thereof so that the soft foam material cannot restore to the original shape. Therefore, when the bumper undergoes collision with high impact, it is necessary to renew the soft foam.

JP-A-H11-208389 discloses a bumper for an automobile which includes a collision energy absorber disposed between a front part of a bumper beam and a bumper fascia. The energy absorber has a lower layer and an upper layer provided on the lower layer and composed of a row of a number of spaced apart blocks arranged with suitable spaces in a car width direction. JP-A-H11-208389 describes that in case of collision against a leg part of a pedestrian, the leg part is advanced in the space between adjacent two blocks by deflection deformation thereof in a car width direction so that an increase of reaction force is suppressed and the collision energy is absorbed by only the lower layer, and that in case of collision against a wall or another automobile, both the upper and lower layers are compression deformed in a front to rear direction. In practice, however, it is difficult with the above bumper structure to satisfy the above requirements (1), (2) and (3) at the same time. Namely, (a) a pedestrian's leg is not always received in the space between adjacent two blocks, (b) therefore, the blocks must be thin and/or soft in order to be deformed laterally and to properly receive a pedestrian's leg therebetween, (c) the upper layer is apt to be broken, and (d) the length of the energy absorber along the front-to-rear direction must be increased to prevent damages of the vehicle so that a compact structure cannot be attained.

BRIEF SUMMARY OF THE INVENTION

It is an object of the present invention to provide a bumper structure which can solve the above problems of the conventional bumpers.

It is another object of the present invention to provide a compact, light weight bumper structure which uses an energy absorbing foam material, which can protect pedestrians, particularly pedestrians' legs and which can

effectively prevent vehicle damages by collision.

It is a further object of the present invention to provide a bumper structure of the above-mentioned type, in which the foam material can withstand one or more collision with a wall or another vehicle.

In accordance with the present invention, there is provided a bumper structure useful for attachment to a front of a vehicle, comprising an elongated bumper beam having a front face provided with at least one rearwardly depressed portion extending lengthwise of said bumper beam, a compressable energy absorbing foam material extending lengthwise of said bumper beam, and a bumper fascia covering said foam material, said foam material having a first portion received in said depressed portion and a second portion protruded forwardly from said front face of said bumper beam such that said second portion is compressed in said depressed portion upon receipt of a collision impact.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of the present invention will become apparent from the detailed description of the preferred embodiments of the invention which follows, when considered in the light of the accompanying drawings, in which:

FIG. 1 is a perspective view schematically illustrating a bumper structure according to the present invention;

FIG. 2 is a cross-sectional view taken on the line II-II in FIG. 1;

FIG. 3 is a sectional view similar to FIG. 2 showing a state in which the bumper of FIG. 2 has collided with a wall;

FIGS. 4(a) through 4(c) are sectional views similar to FIG. 2 showing further embodiments of a bumper

structure according to the present invention;

FIGS. 5(a) through 5(d) are sectional views similar to FIG. 2 showing various further embodiments according to the present invention;

FIG. 6 is a sectional view similar to FIG. 2 showing a further embodiment of a bumper structure according to the present invention;

FIG. 7 is a sectional view showing a state in which the bumper of FIG. 6 has collided with a wall;

FIG. 8 is a sectional view similar to FIG. 6 showing a further embodiment of a bumper structure according to the present invention;

FIG. 9 shows a relationship between the shape recovery of a polypropylene-based resin foam and the number of repetition of compression thereof at various strains;

FIG. 10(a) is a schematic front view of a bumper structure of the present invention subjected to a drop impact test;

FIG. 10(b) is a side view of the bumper structure of FIG. 10(a);

FIG. 11 is a graph showing a relationship between the displacement of a flat impactor and the load generated in the bumper structures of FIG. 10(a) and FIG. 12(a);

FIG. 12(a) is a schematic front view of a known bumper structure subjected to a drop impact test;

FIG. 12(b) is a side view of the bumper structure of FIG. 12(a);

FIG. 13 is a graph showing a relationship between the displacement of a cylindrical impactor and the load generated in the bumper structures of FIG. 10(a) and FIG. 12(a);

FIG. 14 is a sectional view similar to FIG. 2 showing a conventional bumper structure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

A bumper structure according to the present invention is configured to be attached to a front of a vehicle such as an automobile for reducing pedestrian's leg impact on the occasion of collision while preventing vehicle damages by collision with walls, etc.

One preferred embodiment of the bumper structure according to the present invention is illustrated in FIGS. 1 and 2, in which the reference numeral 2 designates an elongated bumper beam. The beam 2, when mounted on a front of a vehicle, extends laterally, namely in the direction normal to the front-to-rear direction (running direction) of the vehicle. The bumper structure is generally curved from side-to-side of the vehicle and the bumper beam 2 is also curved. However, such a curved structure is not essential and other configuration can be used for the purpose of the present invention.

The bumper beam 2 is illustrated as a tubular beam. However, it should be understood that a wide variety of shapes, configurations, materials and processes for the manufacture of the bumper beam 2 are contemplated by the present invention. For example, the beam 2 may be a solid body rather than a hollow body. The cross-section of a hollow beam may be any desired shape, for example, square, rectangular parallelopiped or C-shaped. Any conventionally known bumper beams such as those disclosed in Japanese Kokai Publication Nos. JP-A-H11-78730 and JP-A-2001-322517 may be suitably used for the purpose of the present invention, as long as it can absorb the collision energy through the strain of a hereinafter described energy absorbing foam material and can withstand the collision energy by itself to prevent vehicle damages. Any conventionally used material such as a metal, a plastic or synthetic wood may be used to construct the

bumper beam 2.

The bumper beam 2 has a front face 21 provided with at least one rearwardly depressed portion 22 extending lengthwise of the bumper beam 2. In the embodiment shown in FIGS. 1 and 2, only one depressed portion 22 is provided at an intermediate position between upper end 23 and lower end 24 of the front face 21 to form a U-shaped recess 4.

Designated as 1 is a bumper fascia constituting a front surface of the bumper structure. A compressable energy absorbing foam material 3 is disposed between the fascia 1 and the beam 2. The foam material 3 extends lengthwise of the bumper beam 2 and has a first portion 3a received in the depressed portion 22 and a second portion 5 protruded forwardly from the front face 21 of the bumper beam 2.

In the bumper structure constructed as described above, the second portion 5 of the foamed material 3 is compressed in the U-shaped recess 4 upon receipt of a collision impact. Thus, the bumper structure of the present invention has a relatively small dimension in the front-to-rear direction, even when the foam material 3 has a relatively long front-to-rear length sufficient to protect pedestrian's legs on the occasion of collision. Therefore, the bumper structure can contribute to reduction of size and weight of the vehicle and yet can avoid serious knee injury. Further, vehicle damages can be effectively prevented without adversely affecting freedom of vehicle design.

As the compressable energy absorbing foam material 3, any synthetic resin foam having a suitable cushioning property may be used. The foam material preferably has a compression permanent set (according to JIS K6767-1976) of 20 % or less, more preferably 18 % or less, still more preferably 15 % or less, most preferably at least 10 % or

less. For reasons of excellent elasticity and suitable rigidity, polyolefin-based resin foam is preferably used as the synthetic resin foam. Examples of the polyolefin-based resin include polyethylene-based resins such as linear low density polyethylenes, crosslinked low density polyethylenes and ethylene-styrene copolymers, and polypropylene-based resins such as propylene homopolymers, copolymers of propylene and other olefins and copolymers of propylene and styrene. Polypropylene-based resin foams are particularly preferred for reasons of excellent rigidity, heat resistance and chemical resistance. The foam material 3 may be suitably obtained by molding expanded resin beads in a mold. Expanded non-crosslinked polypropylene-based resin beads, whose surfaces have been modified with an organic peroxide by a method disclosed in Japanese Kokai Publication No. JP-A-2000-167460, are useful for obtaining suitable foam material 3. If desired, the foam material 3 may be used in combination with any other suitable auxiliary cushioning material such as a rubber or a spring. Such an auxiliary cushioning material may be embedded in the foam material 3.

Although not shown in the drawings, the bumper beam 2 may be provided with two or more vertically spaced apart U-shaped recesses 4, if desired. In this case, the foam material 3 may be disposed in at least one of the U-shaped recesses 4 with a portion (second portion 5) thereof being forwardly protruded from the front face 21 of the beam 2. Of course, the foam material 3 may be provided in each of the U-shaped recesses 4. When two or more U-shaped recesses 4 are formed, the dimension and configuration of thereof may be the same or different. Similarly, when two or more foam materials 3 are used, the dimension and configuration thereof may be the same or different.

In the embodiment shown in FIGS. 1 and 2, the depressed portion 22 is formed between the upper and lower

ends 23 and 24 of the front face 21. Alternately, the depressed portion 22 may be formed in at least one of the upper and lower ends 23 and 24 of the front face 21, as shown in FIGS. 5 (a) and 5(b), to form upper stepped portion 11a and/or lower stepped portion 11b in the front face 21. Similarly to the embodiment shown in FIGS. 1 and 2, a foam material 3 extends lengthwise of the bumper beam 2 and has a first portion 3a received in the stepped portion 11a (in the case of FIG. 5(b)) or in each of the stepped portions 11a and 11b (in the case of FIG. 5(a)) and a second portion 5 protruded forwardly from the front face 21 of the bumper beam 2. When two stepped portions 11a and 11b are formed, the dimension and configuration of thereof may be the same or different.

Although not shown, the front face 21 of the bumper beam 2 may be provided one or more stepped portions 11a and/or 11b. In this case, the foam material 3 may be disposed in at least one of the stepped portions 11a and 11b with a portion (second portion 5) thereof being protruded forwardly from the front face 21 of the beam 2. When two or more foam materials 3 are used, the dimension and configuration thereof may be the same or different.

In the bumper structure constructed as described above, the second portion 5 of the foamed material 3 is compressed in the U-shaped recess 4 or in the stepped portion or portions 11a and/or 11b upon receipt of a collision impact. Thus, the bumper structure of the present invention has a relatively small dimension in the front-to-rear direction even when the foam material 3 has a relatively long front-to-rear length sufficient to protect pedestrian's legs on the occasion of collision. In other words, it is easy to design the bumper structure according to the present invention such that the compression load generated therein by collision at a given impact energy is below the desired upper limit load and

yet the weight and size thereof are small. The term "desired upper limit load" as used herein is intended to refer to a compression load below which a pedestrian's leg would not be seriously damaged by the collision at no more than the given impact energy.

It is without saying that the rearwardly depressed portion 22 must withstand the energy exerted by the compression of the foam material 3 caused by the collision of the vehicle.

Further, the bumper structure of the present invention can prevent vehicle damages upon collision with a wall or another vehicle. FIG. 3 schematically depicts a state in which the bumper structure of FIG. 2 is collided with a wall 24. The second portion 5 of the foam material 3 (FIG. 2) has been fully compressed in the U-shaped recess 4. Thus, the collision energy is then absorbed by the beam 2 to protect the vehicle. In this case, since the foam material 3 has a sufficient length and does not cause bottoming out, the bumper structure does not loose its function to prevent pedestrians from being seriously damaged. Namely, since no bottoming out is caused, the foam material 3 can recover the original shape without a substantial loss of its energy absorbing function. Thus, the bumper structure of the present invention can simultaneously attain the effects of (1) prevention of damages of the vehicle, (2) protection of pedestrians and (3) compact and light weight structure. Moreover, the foam material 3 is prevented from being further compressed beyond the state as shown in FIG. 3 and, therefore, can restore to the original state and can be reused for protecting pedestrians, when the impact is removed. Namely, even when the bumper undergoes repeated collision, the foam material 3 can serve to protect pedestrians.

It is, therefore, preferred that the bumper structure have a design which prevents the foam material 3

from bottoming-out. For example, since the compression load of a foam material made from a foamed polypropylene beads molding abruptly increases when the strain exceeds about 60 to 70 %, the bottoming-out of the foam material may be prevented when about at least 30 to 40 % of the total length (L1) of the foam material 3 is received in the rearwardly depressed portion 22.

In FIG. 1 and FIGS. 5(a) and 5(b), the foam material 3 is illustrated as a rectangular parallelopiped body. However, it should be understood that a wide variety of shapes and configurations of the foam material 3 are contemplated by the present invention. For example, the front end of the foam material 3 can be rounded to conform to the inside wall of the bumper fascia 1. One or more weight reducing portions such as recesses, holes and grooves may be formed in any desired surface (such as front surface and upper or lower surfaces) of the material 3 or inside thereof. Further, the foam material 3 may not be closely fitted in the U-shaped recess 4 or stepped portion 11a or 11b, although, from the standpoint of design efficiency, the foam material 3 is suitably closely fitted thereinto.

The rigidity and the dimensions of the foam material 3 are suitably determined so that (a) the bumper structure can protect a pedestrian on the occasion of collision without seriously injuring the pedestrian's leg and (b) the foam material 3 can restore to the original shape even when the vehicle collides with another vehicle or a wall. The rigidity of the foam material 3 depends upon the apparent density and the kind of the base resin thereof. The vertical length of the foam material 3 is generally not greater than the vertical length of the depressed portion 22 and the lateral length of the foam material 3 is generally not greater than the lateral length of the fascia 1.

As used herein, the term "vertical length" of the foam material 3 and the depressed portion 22 is intended to refer to the length thereof along the vertical direction of the vehicle to which the bumper structure has been mounted. The term "lateral length" of the foam material 3 and the fascia 1 is the length thereof along the lateral direction (side-to-side direction) of the vehicle to which the bumper structure has been mounted. Similarly, the term "front-to-rear length" of the foam material 3 is the length thereof along the front-to-rear direction (running direction) of the vehicle to which the bumper structure has been mounted.

The vertical length of the depressed portion 22 of the beam 2 (when the beam 2 has two or more depressed portions 22, a total length of the vertical lengths of the depressed portions 22) is generally 30 to 80 %, preferably 40 to 70 %, of the vertical length of the beam 2.

There is a demand for a bumper core which can absorb energy of collision between the pedestrian and the automobile traveling at a relatively high speed of, for example, 40 km/hour, so that serious knee injury can be avoided. In this respect, the design of the foam material 3 plays an important role, though the energy to be absorbed by the foam material 3 varies depending upon kinds of the vehicle to which the bumper structure is mounted, since the collision energy is also absorbed by other parts of the bumper structure such as the fascia 1, beam 2 and a front skirt with which pedestrians' ankles may collide. Generally, however, the bumper structure preferably has a design which prevents the foam material 3 from bottoming-out. Thus, in the case of a foam material made from a foamed polypropylene beads molding, for example, the compression load abruptly increases when the strain exceeds about 60 to 70 %, the bottoming-out of the foam material may be prevented when about at least 30 to

40 % of the total length (L1) of the foam material 3 is received in the rearwardly depressed portion 22. In this case, the full length of the protruded, second portion 5 (length: L2) can be utilized for absorbing the collision energy without bottoming out thereof, namely, without generating a high load.

It is preferred that the bumper structure can not only protect pedestrians but also permit the foam material 3 to be reusable even after one or repeated collision with walls or other vehicles. This can be achieved by selecting a ratio L2/L1 so as to permit the elastic recovery of the foam material 3 while selecting the length L2 of the second portion 5 of the foam material 3 such that the load generated therein by collision at a given impact energy is below the desired upper limit load. For reasons of satisfactory bottoming-out prevention, satisfactory protection of pedestrian and satisfactory reusability of the foam material 3 while suppressing the length thereof, it is preferred that the ratio of the length L2 of the second portion 5 to the length L1 of the foam material 3 (L2/L1) be in the range of 0.4 to 0.9, more preferably 0.5 to 0.8, most preferably 0.5 to 0.7. Further, it is preferred that L1 be in the range of 40 to 150 mm, more preferably 50 to 130 mm, most preferably 60 to 120 mm. The foam material 3 is preferably located such that the rear end thereof is abutted against the bottom of the depressed portion 22.

Various modifications may be made to the bumper beam 2 and foam material 3. Examples of some modifications are shown in FIGS. 4(a) to 4(c), in which the same reference numerals as those in FIGS. 1 and 2 designate similar component parts. In the embodiments shown in FIG. 4(a) to 4(c), upper and lower parts of the front face 21 of the beam 2 are not coplanar. In this case, the length L1 of the foam material 3 is the length from the foremost end to

the rearmost end of the foam material 3 along the front-to-rear direction, and the length L2 of the protruded, second portion 5 is the length between the foremost portion of the front face 21 and the foremost end of the foam material 3 (the length of the portion hatched with double lines in FIGS. 4(a) to 4(c)) along the front-to-rear direction. L3 represents the depth of the depressed portion 22 (recess 4 or stepped portion 11a or 11b) and is the length between the bottommost portion of the depressed portion and the foremost portion of the front face 21 along the front-to-rear direction.

A further preferred embodiment of the present invention is illustrated in FIGS. 6 and 7, in which the same reference numerals as those in FIGS. 1 and 2 designate similar component parts. In this embodiment, an energy absorbing body 6 is provided at a front end of the second portion 5 of the foam material 3. The energy absorbing body 6 has a vertical length greater than the vertical length of the depressed portion 22 so that, as shown in FIG. 7, when the bumper structure is collided with a wall 24 or another vehicle, the energy absorbing body 6 is in contact with the front face 21 to absorb part of the collision energy. Therefore, it is possible to reduce the rigidity and other mechanical strengths of the bumper beam 2. Therefore, the above embodiment can contribute to reduction of the weight of the bumper structure.

In the above embodiment, it is preferred that the energy absorbing body 6 be brought into contact with the bumper beam 2 only after the foam material 3 has been fully compressed into U-shaped recess 4 and has assumed the position as shown in FIG. 7. When the energy absorbing body 6 is made of a material which is harder than the foam material 3 and when the energy absorbing body 6 has such a configuration or shape as to be

contacted with the beam 2 before the foam material has been fully compressed into the recess 4, a compression load which is greater than the desired upper limit load may be generated in the energy absorbing body 6 so that the pedestrian will not be protected.

FIG. 5(c) depicts an embodiment in which the above-described energy absorbing body is applied to the bumper structure in which a depressed portion 22 is provided in each of upper and lower ends 23 and 24 of a front face 21 to form upper and lower stepped portions 11a and 11b. The energy absorbing body is designated as 12 and is an integrated body to which each of tip ends of upper and lower foam materials 3 received in the stepped portions 11a and 11b is secured. The function and features of the energy absorbing body 12 are the same as those of the energy absorbing body 6 of FIG. 6 and are not repeated here.

The energy absorbing body 6 or 12 may be made of any desired material and may be, for example, a synthetic resin foam body, a non-foamed synthetic resin body, a metal honeycomb body or a rubber body. A synthetic resin foam body is preferably used since the energy absorbing characteristics thereof can be easily controlled by the apparent density thereof and since the design thereof may be suitably determined in match with the limited available space within the bumper structure. A resilient foam body similar to the foam material 3 may be particularly suitably used as the energy absorbing body 6 or 12 for reasons of good shape recovery characteristics. Such a foam body may be suitably made from a foamed molding of expanded resin beads.

The energy absorbing body 6 or 12 is desirably integrated with the foam material 3 into a unitary structure for reasons of easiness of assembling works of the bumper structure. Integration may be by using an

adhesive, by fuse-bonding or by using any suitable connecting means. Alternatively, energy absorbing body 6 or 12 when made of a resin foam may be molded together with the foam material 3 into a single foamed molding. As long as the energy absorbing body 6 or 12 is maintained in a fixed position inside the fascia 1, such an integrated structure is not essential.

The energy absorbing body 6 or 12 made of a resin foam preferably has a greater apparent density (preferably 0.64 to 0.225 g/cm^3) than that of the foam material 3. In this case, the collision energy which remains unabsorbed by the foam material 3 is absorbed by the energy absorbing body 6 or 12, so that the beam 2 receives a reduced collision energy. However, the apparent density of the energy absorbing body 6 or 12 made of a resin foam may be in the range of 0.026 to 0.064 g/cm^3 when further protection of pedestrians is intended.

The energy absorbing body 6 or 12 need not be a uniform material but may be a composite material. For example, as shown in FIG. 8, the energy absorbing body 6 may be composed of a center region 7 made of a resin foam (which may be made of the same foam and may have the same apparent density as those of the foam material 3) and upper and lower regions 8 connected to the center region 7 and made of a different material such as a resin foam having a higher apparent density than that of the center region 7. The energy absorbing body 6 composed of the center, upper and lower regions 7 and 8 may be prepared by bonding these regions using an adhesive, by fuse-bonding or by using any suitable connecting means. Alternatively, energy absorbing body 6 (or 12) when made of a resin foam may be molded in a mold. For example, expanded beads having different densities are filled in respective chambers of a mold cavity partitioned by a partition plate (in the form of a straight plate, a corrugated plate or a

comb-like plate). After the removal of the partition plate, the mold is closed and heated to produce a composite molding.

FIGS. 5(a), 5(b) and 5(d) show further embodiments of the present invention using an energy absorbing body 13 which is similar to the energy absorbing body 6 or 12. The energy absorbing body 13 is provided on a portion of the front face 21 other than the depressed portion 22 and serves to function in the same manner as the energy absorbing body 6 or 12. Preferably, the energy absorbing body 13 is fixed to the surface of the front face 21 by, for example, using an adhesive. When the thickness of the energy absorbing body 13 along the front to rear direction is represented by L4, the ratio (L2-L4)/L1 is preferably in the range of 0.4 to 0.9, more preferably 0.5 to 0.8, most preferably 0.5 to 0.7 (L1 and L2 are as defined above). Further, it is preferred that the length L1 be in the range of 40 to 150 mm, more preferably 50 to 130 mm, most preferably 60 to 120 mm. It is also preferred that the thickness L4 be in the range of 10 to 70 mm, more preferably 15 to 50 mm. The foam material 3 is preferably located such that the rear end thereof is abutted against the bottom of the depressed portion 22.

As used herein the term "apparent density" of the foam material 3 and the energy absorbing bodies 6, 12 and 13 made of a resin foam is defined by the formula D1 = W1/V1 wherein D1 represents the apparent density thereof, W1 represents the weight thereof and V1 represents the volume thereof. The volume V1 is measured by an immersion method in which the specimen is immersed in water contained in a graduation cylinder. From the increment of the volume, the volume V1 can be determined.

As described previously, polyolefin-based resin foam is preferably used as the compressable energy absorbing foam material 3. The term "polyolefin-based resin foam"

is intended to refer to a foam made of a base resin containing a polyolefin-based resin in an amount of at least 60 % by weight, preferably 80 to 100 % by weight. Examples of the polyolefin-based resin include polyethylene-based resins such as high density polyethylenes, low density polyethylenes, linear low density polyethylenes, and polypropylene-based resins such as described below. The polyolefin-based resin may contain no more than 50 % by weight, preferably no more than 40 % by weight, more preferably no more than 20 % by weight, of one or more comonomers other than olefinic monomers such as styrene.

Among polyolefin-based resin foams, foams obtained from polypropylene-based resins, especially foams obtained by molding polypropylene-based resin beads in a mold are particularly preferably used as the foam material 3 for reasons of excellent rigidity, heat resistance, chemical resistance and easiness in molding into desired shapes. A foam obtained from polypropylene-based resin beads has an additional merit that the cross-sectional area thereof scarcely increases when the foam is compressed. Thus, the foam material 3 when made of such a polypropylene-based resin foam can be suitably compressed into the U-shaped recess 4 or stepped portion 11a or 11b at a time of collision.

Examples of the polypropylene-based resin include propylene homopolymers, copolymers of propylene and styrene and copolymers of propylene and other olefins such as propylene-butene block copolymers, propylene-butene random copolymers, ethylene-propylene block copolymers, ethylene-propylene random copolymers, ethylene-propylene-butene random copolymers. Propylene homopolymers are particularly preferably used, since a foam produced from expanded propylene homopolymer beads has excellent collision energy absorbing efficiency.

A foam obtained by molding the polypropylene-based resin beads in a mold (hereinafter referred to simply as PP molding) suitably used as the foam material 3 preferably has an apparent density of 0.11 to 0.025 g/cm^3, more preferably 0.09 to 0.04 g/cm^3, for reasons of excellent compression characteristics, namely satisfactory protection of pedestrians while reducing the weight and size of the bumper structure. It is not necessary that the foam material 3 should have a uniform apparent density throughout its whole body. Rather, the foam material 3 may be composed of two or more parts having different apparent densities. In such a case, the apparent density of the foam material 3 is obtainable by dividing the total weight thereof by the whole volume thereof.

FIG. 9 shows a relationship between the shape recovery of a PP molding and the number of repetition of the compression operation at various compression strains. A cubic body (80mm × 80mm × 80mm) of a PP molding having an apparent density of 0.082 g/cm^3 is placed between a pair of pressing plates and compressed at a compression speed of 50 mm/minute. As soon as a given strain percentage has reached, the pressing plates are moved back at a speed of 50 mm/minute. 30 minutes after the release of the pressure, the thickness (D) of the compressed cube body is measured. The shape recovery is calculated according to the following formula:

Shape recovery (%) = D/80 × 100.

Similar compression and measurement of the thickness is repeated 4 times in total. The results are shown in FIG. 9 in which the curves a to d are the results for 20 % strain (compressed by 16 mm), 50 % strain (compressed by 40 mm), 70 % strain (compressed by 56 mm) and 90 % strain (compressed by 72 mm), respectively. The results shown in FIG. 9 indicate that more than 80 % shape recovery is obtainable even when subjected to 4 compression treatments

as long as the strain is 70 % or less.

In the bumper structure according to the present invention, since the compression strain may be controlled by control of the L2/L1 ratio (or (L2-L4)/L1 ratio), it is easy to design suitable bumper structure capable of protecting pedestrians while preventing an increase of the front-to-rear length thereof.

Although the foregoing embodiments are concerned with bumper structures suitable for attachment to a front of a vehicle, it is without saying that the bumper structure of the present invention is not limited to such applications. The bumper structure may be used for protecting any required potions (such as thighs and hips) of pedestrian's body while preventing damages of the vehicle body.

The following examples will further illustrate the present invention.

Example 1

A synthetic wood body as shown in FIGS. 10(a) and 10(b) was used as a bumper beam 2. The beam 2 had a height T (along a vertical direction) of 120 mm, a length D (along a lateral direction) of 300 mm and a width H1 (along a front to rear direction) of 80 mm and had a front face provided with a U-shaped recess extending throughout the length of the beam and having a height t1 of 40 mm and a depth L3 of 40 mm. As an energy absorbing foam material 3, a rectangular parallelopiped foamed molding of expanded polypropylene-based resin beads (expanded beads of a propylene-ethylene random copolymer having a tensile modulus of 1,120 MPa) having an apparent density of 0.082 g/cm^3, a height t1 (along a vertical direction) of 40 mm, a length d (along a lateral direction) of 150 mm and a width L1 (along a front to rear direction) of 80 mm was used.

The energy absorbing foam material 3 was fitted into the U-shaped recess of the beam 2 as shown in FIG. 10 so that the foam material had a portion protruded from the front face of the beam 2 having a length L2 of 40 mm. The front surface of the foam material 3 was covered with a bumper fascia 30 made of a synthetic resin and having a thickness of 3 mm to form a bumper.

The bumper was subjected to a drop impact test using a drop impact dynamic tester. Thus, the bumper was placed on a stand 50 of an impact dynamic tester with the outer surface of the fascia 30 facing upward and being kept horizontal. A steel impactor (weight: 16 kg, size: 40 cm length × 40 cm width × 3 cm thickness) having a flat lower surface and positioned above the fascia 30 at a distance of 103 cm from the fascia 30 was allowed to free fall on the fascia 30 such that lower surface of the impactor was kept horizontal, such that the flat lower surface of the impactor collided with the flat outer surface of the fascia 30. In this case, the impact energy was about 162 J. A relationship between the displacement of the impactor and the load generated in the bumper structure was measured to give the results shown in FIG. 11, curve "a". As will be appreciated from FIG. 11, the maximum displacement was about 33 mm and the maximum load generated was about 7 kN.

Comparative Example 1

A synthetic wood body as shown in FIGS. 12(a) and 12(b) was used as a bumper beam. The beam had a height T (along a vertical direction) of 120 mm, a length D (along a lateral direction) of 300 mm and a width H2 (along a front to rear direction) of 80 mm. As an energy absorbing foam material, a rectangular parallelopiped foamed molding of expanded polypropylene-based resin beads (expanded beads of a propylene-ethylene random copolymer having a

tensile modulus of 1,120 MPa) having an apparent density of 0.082 g/cm^3, a height t2 (along a vertical direction) of 80 mm, a length d (along a lateral direction) of 150 mm and a width L1 (along a front to rear direction) of 40 mm was used. The front surface of the foam material was covered with a bumper fascia 30 made of a synthetic resin and having a thickness of 3 mm to form a bumper.

The bumper was subjected to a drop impact test using a drop impact dynamic tester in the same manner as that of Example 1. A relationship between the displacement of the impactor and the load generated in the bumper structure was measured to give the results shown by the curve "b" in FIG. 11. As will be appreciated from FIG. 11, the maximum displacement was about 17 mm and the maximum load generated was about 16 kN which was much higher than that of the bumper structure of Example 1.

Example 2

A synthetic wood body as shown in FIGS. 10(a) and 10(b) was used as a bumper beam 2. The beam 2 had a height T (along a vertical direction) of 120 mm, a length D (along a lateral direction) of 300 mm and a width H1 (along a front to rear direction) of 80 mm and had a front face provided with a U-shaped recess extending throughout the length of the beam and having a height t1 of 35 mm and a depth L3 of 50 mm. As an energy absorbing foam material 3, a rectangular parallelopiped foamed molding of expanded polypropylene-based resin beads (expanded beads of a propylene-ethylene random copolymer having a tensile modulus of 1,120 MPa) having an apparent density of 0.082 g/cm^3, a height t1 (along a vertical direction) of 35 mm, a length d (along a lateral direction) of 100 mm and a width L1 (along a front to rear direction) of 100 mm was used.

The energy absorbing foam material 3 was fitted into

the U-shaped recess of the beam 2 as shown in FIG. 10 so that the foam material had a portion protruded from the front face of the beam 2 having a length L2 of 50 mm. The front surface of the foam material 3 was covered with a bumper fascia 30 made of a synthetic resin and having a thickness of 3 mm to form a bumper.

The bumper was subjected to a drop impact test using a drop impact dynamic tester. Thus, the bumper was placed on a stand 50 of an impact dynamic tester with the outer surface of the fascia 30 facing upward and being kept horizontal. A cylindrical steel impactor (weight: 21.4 kg, outer diameter: 70 mm) positioned above the fascia 30 at a distance of 715 mm from the fascia 30 was allowed to free fall on the fascia 30 such that the axis of the cylindrical impactor was oriented normal to the lengthwise direction of the bumper beam 2. In this case, the impact energy was about 150 J. A relationship between the displacement of the impactor and the load generated in the bumper structure was measured to give the results shown in FIG. 13, curve 1. As will be appreciated from FIG. 13, the maximum displacement was about 45 mm and the maximum load generated was about 3.5 kN.

Comparative Example 2

A synthetic wood body as shown in FIGS. 12(a) and 12(b) was used as a bumper beam. The beam had a height T (along a vertical direction) of 120 mm, a length D (along a lateral direction) of 300 mm and a width H2 (along a front to rear direction) of 80 mm. As an energy absorbing foam material, a rectangular parallelopiped foamed molding of expanded polypropylene-based resin beads (expanded beads of a propylene-ethylene random copolymer having a tensile modulus of 1,120 MPa) having an apparent density of 0.082 g/cm^3, a height t2 (along a vertical direction) of 35 mm, a length d (along a lateral direction) of 100 mm

and a width L1 (along a front to rear direction) of 50 mm was used. The front surface of the foam material was covered with a bumper fascia 30 made of a synthetic resin and having a thickness of 3 mm to form a bumper.

The bumper was subjected to a drop impact test using a drop impact dynamic tester in the same manner as that of Example 2. A relationship between the displacement of the impactor and the load generated in the bumper structure was measured to give the results shown by the curve 2 in FIG. 13. As will be appreciated from FIG. 13, the maximum displacement was about 42 mm and the maximum load generated was about 5.3 kN.

In the impact tests in Example 2 and Comparative Example 2, the outer diameter of the cylindrical impactor of 70 mm is selected to represent an approximate diameter of an adult leg. In order to protect a pedestrian's leg, it is necessary for a bumper to sufficiently absorb impact energy while suppressing the leg impact so that serious injury is not caused. Under the above test conditions, the load generated is desired to be 3.5 kN or less. The bumper structure of Example 2 can fully absorb the collision energy and can maintain the generated energy in the desired range. In the case of Comparative Example 2, the load generated exceeds 3.5 kN when the displacement is greater than 30 mm because the foam material has been compressed with a strain of 70 % or more (bottoming-out), though the bumper structure can fully absorb the collision energy. In order to reduce the generated load in the case of Comparative Example 2, it is necessary to increase the length L1 of the foam material.